What made GRBs 060505 and 060614?

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Abstract

Recent observations of two nearby SN-less long-duration gamma-ray bursts (GRBs), which share no obvious characteristics in their prompt emission, suggest a new phenomenological type of massive stellar death. Here we briefly review the observational properties of these bursts and their proposed hosts, and discuss whether a new GRB classification scheme is needed.

Key words: Gamma rays: bursts, Supernovae: general
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1 Introduction

A broad-lined and luminous type Ic core-collapse supernova (SN) is predicted to accompany every long-duration gamma-ray burst (GRB) in the standard collapsar model (Woosley, 1993). Although this association had been confirmed in observations of several nearby GRBs (e.g. Hjorth et al., 2003), a new controversy commenced when no SN emission accompanied GRBs 060505 ($z = 0.09$, duration ∼4 s) and 060614 ($z = 0.13$, duration ∼100 s) down to limits fainter than any known type Ic SN and hundreds of times fainter than the archetypal SN 1998bw (Della Valle et al., 2006; Fynbo et al., 2006; Gal-Yam et al., 2006). The upper panels of Fig.1 illustrate how easily such SNe would have been detected in the case of GRB 060505.

An important clue to the origin and progenitors of these bursts, is the nature of the host galaxies. The GRB 060505 host is a spiral galaxy, atypical for long-duration bursts but not unheard of (GRB 980425: Fynbo et al., 2000; GRB 990705: Le Floc'h et al., 2002; GRB 020819: Jakobsson et al., 2005). The burst occurred inside a compact star-forming H II region in one of the spiral arms, and a spatially resolved spectroscopy (lower panel of Fig.1) revealed that the properties of the GRB site are

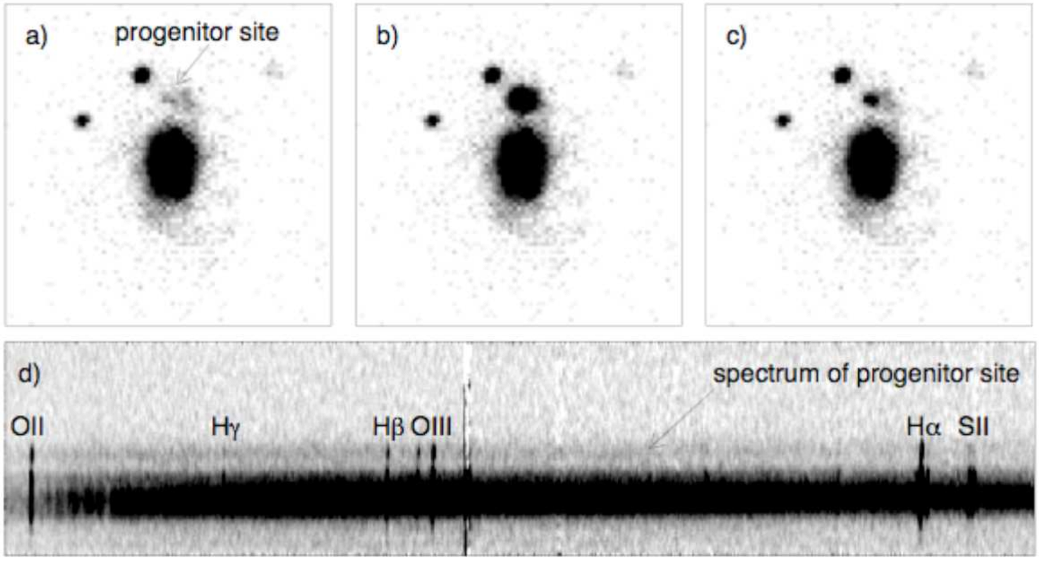

Fig. 1. (a) The field (20″× 20″) of GRB 060505 as observed from the VLT in the R-band on 22 May 2006. The arrow marks the position where the optical afterglow was detected in earlier imaging. (b) As the image would have looked had a SN like 1998bw been present in the data. The strict upper limits strongly exclude the bright SNe 1998bw and 2006aj that were associated with long GRBs. (c) Similar to (b), but with a very faint Ic SN, such as 2002ap, added. (d) The 2-D optical spectrum obtained with VLT/FORS2. The slit covered the centre of the host galaxy and the location of GRB 060505. As seen in the spectrum, this site is a bright star-forming region in the host galaxy suggesting that the progenitor was a massive star.

similar to those found for other long-duration GRBs with a high specific star formation rate (SSFR) and low metallicity (Thöne et al., 2007). The GRB 060614 host is significantly fainter (one of the least luminous GRB host ever detected) with a moderate SSFR.

2 Discussion

2.1 High extinction?

Could the emission from an associated SN be completely obscured by dust along the line-of-sight? The levels of Galactic extinction are very low in both directions. Host extinction of more than a magnitude is also unlikely in either case since the host galaxy spectra display no reddening as derived from the Balmer line ratios. In addition, the GRB 060614 afterglow is clearly detected in the UV (Holland, 2006).

2.2 Wrong redshifts?

Another option is that the proposed host galaxies are chance encounters along the line-of-sight (Cobb et al., 2006; Schaefer & Xiao, 2006), and the real GRB redshifts are much higher (rendering a SN too faint to be observed). However, a few ob-

servational facts argue against this scenario. In the case of GRB 060614: (i) the UV detection places an upper limit of around 1.1 on the redshift; (ii) no absorption components in the optical afterglow spectrum (Fugazza et al., 2006), as expected for a low redshift, but not for a high-z burst with a foreground galaxy; (iii) very deep HST images of the field should have revealed the "true host" at $z \lesssim 1.1$, but none was seen (Gal-Yam et al., 2006). For GRB 060505 it is extremely unlikely that the afterglow accidentally superposed right on top of a small star-forming region within a foreground spiral galaxy.

2.3 No SNe: a problem?

The host galaxies and the GRB location within them strongly suggest an association with star formation, and hence a massive stellar origin. It is important to realize that the lack of a strong SN emission was actually predicted as a variant of the original collapsar model, e.g. collapse of a massive star with an explosion energy so small that most of the ^{56}Ni falls back into the black hole (e.g. Heger et al., 2003; Fryer et al., 2006). In another variant of the collapsar model, progenitor stars with relatively low angular momentum could also produce SN-less GRBs (MacFadyen, 2003).

We should also remember that the duration distributions of short and long GRBs overlap. In fact, the GRB 060505 duration of 4 s is near the ~5 s duration which Donaghy et al. (2006) find as the point of roughly equal probability of a given burst lying in either the short or long class. It has been suggested that the physical mechanism for this burst is the same as for short bursts, i.e. a merger of compact objects (Ofek et al., 2007), although the progenitor time delay of only $\lesssim 7$ Myr is on the borderline for allowed values (Thöne et al., 2007). However, such short time delays have been proposed via newly recognized formation channels, which lead to the formation of tighter double compact objects with short lifetimes and therefore possible prompt merger within hosts (Belczynski, 2007). Whether such channels require a low metallicity as found for GRB 060505 (Thöne et al., 2007) remains to be explored.

2.4 Classification problem?

With the added complication that the ~100 s long GRB 060614 is located among the short bursts in the lag-luminosity plot, it has been argued that a new GRB classification scheme is required (Gehrels et al., 2006). We do not think this is the case, as the current GRB classification is operationally well defined. Rather that new observations are warning us not necessarily to expect a very simple mapping between the duration of the GRB and the nature of the progenitor: long bursts (>2 s) synonymous with massive stars and short bursts (<2 s) synonymous with compact object mergers.

Others want to abandon the long-

short paradigm altogether due to these "oddball" bursts, and invent a new terminology: Type I and II bursts similar to the SN classification scheme (Zhang et al., 2007). In this scheme, eight different properties have to be considered for each burst/host. However, this scheme can be ambiguous (e.g. GRB 060505) and is not operational, i.e. involves observables that are not available for most bursts (associated SN). Using proposed hosts (i.e. a nearby bright galaxy) to make a distinction between the two burst populations can also be risky (e.g. GRB 060912A: Levan et al., 2007). In addition, one might envisage a Type III category consisting of the new type of bursts (massive white dwarf/neutron star merger) suggested by King et al. (2007). These could produce long bursts definitely without an accompanying SN and have a strong correlation with star formation. However, rare members of the class need not be near star-forming regions, and could have any type of host galaxy.

It is clear that the two SN-less long bursts from last summer have raised a few warning flags, i.e. how we think about the long/short dichotomy. At this point in time, we only recommend that people keep an open mind.

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